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# WASTEWATER DISPOSAL: MEASUREMENT OF SOIL ABSORPTION

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## ABSTRACT

Failures of septic tank effluent subsurface disposal systems result from an incomplete understanding of the hydraulic conductivity of the soil into which they are disposed. Percolation tests are generally performed with "clean" water (low electrical conductivity, low total dissolved salts). Few tests, if any, are conducted with water of a quality which approaches that of the effluent .

The author developed a method of extracting small undisturbed cores for the soil under investigation, measuring saturated hydraulic conductivity (Ksat) using water of various chemical compositions and relating the changes in Ksat to disposal mechanism. Undisturbed cores were wrapped in heat shrink plastic and treated as for other methods employing Darcy's equation .

The results from laboratory tests, of soil horizons at various depths, of effluents with different chemical qualities indicate different management goals for safe and efficient disposal. The changes in Ksat with respect to effluent quality indicate that sodium adsorption ratios, electrolyte concentration and pH induced losses in Ksat of up to 100-fold relative to "clean" water.

## KEYWORDS

On-site; septic tank; saturated hydraulic conductivity; undisturbed cores; disposal; sodium adsorption ratio; soil sampling.

## SEPTIC TANK EFFLUENT DISPOSAL

### Wastewater Disposal

Of the estimated 1.7 million residences in New South Wales connected to a reticulated mains water supply 130 000 treat domestic effluent in septic tanks (ABS, 1987). The majority of households not connected to mains water (120 000) also dispose of their household wastewater to a septic tank. A great proportion of these 250 000 tanks dispose of effluent via a sub-surface drainfield under various soil conditions.

The partially treated effluent flows, under low head and in response to a surcharge into the tank, from the septic tank into an underground trench system. In some systems a pre-treatment (sand) filter may be installed prior to soil disposal. The hydraulic head created by ponding supposedly increases infiltration into the surrounding soil profile. The sedimentation of organic suspended solids removes much of the clogging material before effluent enters the soil disposal field, a more positive application of efficient treatment.

In reality, the effluent ponds within the trench, undergoing further anaerobic digestion and forms a layer of polysaccharides and iron sulphides on the soil/effluent interface (Otis, 1977). Hydraulic properties are reduced, infiltration lowered and ponding increased until the liquid appears at the surface. The environment surrounding the drainfield becomes saturated, increasing the problems of smell, unsightly wet spots, and potential for runoff into neighbouring properties or waterways. At this point the system has failed and is a serious source of pollution (SPCC, 1987).

## System Failures

Many of the subsurface drainfield failures result from an incomplete understanding of the hydraulic conductivity of the soil. However, an analysis of the soil profile for the disposal of wastewater from septic tank and various sources is fraught with difficulties. A small number of recordings of percolation tests at any one site are often extrapolated to the likely long term percolation rate (saturated hydraulic conductivity - Ksat). Most tests are carried out in a few hours (less than 8 hours) and typically use clean water for the liquid medium.

A recent survey by the author of all local government Health Surveyors in New South Wales indicated that although guidelines for soil testing were readily available, more than 65% of the respondents did not undertake any test but relied upon local experience for design of subsurface drainfields. Of the 35% who used the standard percolation test (clean water is recommended), only 60% nominated a design length of more than 20 metres for a family of 5 persons. Under most eastern Australian conditions 20 metres is not considered of sufficient length for adequate disposal. Brouwer and Bugeja (1980) suggest lengths in excess of 100 metres on duplex soils in Victoria at lower rainfall values than New South Wales.

Surface and subsurface disposal of other wastewaters suffer a similar fate, inadequate measurement of hydraulic conductivity and a loss of soil physical qualities (through dispersion) due to dissolved salts in the liquid waste. Tests based upon clean water do not reflect the potential changes to soil physical properties through dispersion and flocculation.

## Field Measurement of Hydraulic Conductivity

Common methods for measuring infiltration and percolation include standard percolation test based upon Ryon's test (McGauhey and Krone, 1967; Winneberger, 1984), double ring infiltrometer (Bligh,1978) rapid well permeameter (Talsma and Hallam, 1980) or saturated hydraulic conductivity tests in constant or falling head permeameters employing Darcy's equation (Means and Parcher, 1963). In the case of the latter, disturbed cores are usually prepared from sieved samples, manually packed to bulk densities approximating the soil under investigation and subjected to constant or falling head gradients of infiltrating water.

Sound analyses of the results are difficult and expensive to obtain in field measurements where large areas are involved. Laboratory methods are usually restricted to reconstituted disturbed samples (Loveday, 1978) and mostly preformed using water as infiltrating liquid. Analysis by researchers such as Jayawardane (1979), Shainberg *et al*, (1981) have used disturbed cores to quantify infiltration using a variety of effluents to express the reduction in saturated hydraulic conductivities with electrolyte and sodium ion concentrations.

The extraction of undisturbed cores has been difficult, particularly where saturated hydraulic conductivity testing is required. A method of extracting an undisturbed soil core (Patterson and Cass, 1988), wrapping the core in a plastic tube and then heat shrinking the plastic in a tight shroud around the sample has been developed by the author. The samples can be obtained in sufficient numbers (up to 30 cores per hour) at a reasonable cost to permit statistical analysis of the variability common to the measurement of soil's physical properties.

## UNDISTURBED SOIL CORES

### Undisturbed Soil Core Preparation

An electric hydraulic soil sampler, fitted to the bullbar of a four wheel drive vehicle is used to obtain the soil sample. A tube of 51 mm external diameter is hydraulically driven vertically into the soil profile to a depth of approximately 800 mm (further extensions are possible). The system exploits the greater weight of the front of the vehicle and the proximity to the battery to reduce voltage drop to the electric motor.

Special cutting tips, designed by the Department of Primary Industry, Queensland, are silver soldered to the tube to cut the sample with minimal compression to, or deformation of the soil's structural properties.

The undisturbed sample can be broken into portions, about 60-80 mm long, at locations which represent a particular depth in the profile. The samples are broken to avoid smearing of soil surfaces or distorting micropores at the upper and lower surfaces.

Figure 1. Hydraulic Soil Sampler attached to front of vehicle

Comparisons between bulk density measurements for undisturbed cores, extracted as above, and standard hammer ring tests were made by Patterson and Cass, (1988) for four clay soils. Results obtained using the hydraulically driven sampler tubes (43.7 mm sample diameter) were consistent with the bulk density of samples obtained using 76 mm hammered rings. Minor variations were greatest in the Black Earths, possibly due to macropores within the soil. Based upon similar bulk densities, compared with field values, the undisturbed cores were considered representative of the field condition and applicable to hydraulic conductivity measurements.

Undisturbed cores to 800 mm were obtained from a single sampling, each core taking about 2 minutes to obtain and a further 2 minutes for labelling and packing for transport to the laboratory. Soil cores were packed in longitudinally sliced sections of 50 mm uPVC tube to avoid damage to either the surface or the density of the sample. Moisture was retained by wrapping in plastic bags and sealing with elastic band. A duplicate sample can be used for soil description, chemical analysis, bulk density measurements and other tests as required.

## Sample Preparation

The undisturbed sample is placed within a sleeve of heat shrink plastic and subjected to a blow heater (approx. 540°C) for 3-5 seconds. During the shrinking operation, a reservoir is moulded into the upper portion of the sleeve and a funnel formed under the soil sample. The wrapped core is then set up in a device which maintains a constant head above the soil core.

The sleeved cores are prepared with an upper reservoir to maintain a constant head of approximately 30 mm above the undisturbed core. Through-flow can then be measured within the laboratory, Ksat calculated using Darcy's equation and analysis performed on a large number of samples over a long monitoring period. Where necessary, the sample can be flushed with carbon dioxide or saturated by immersion in water.

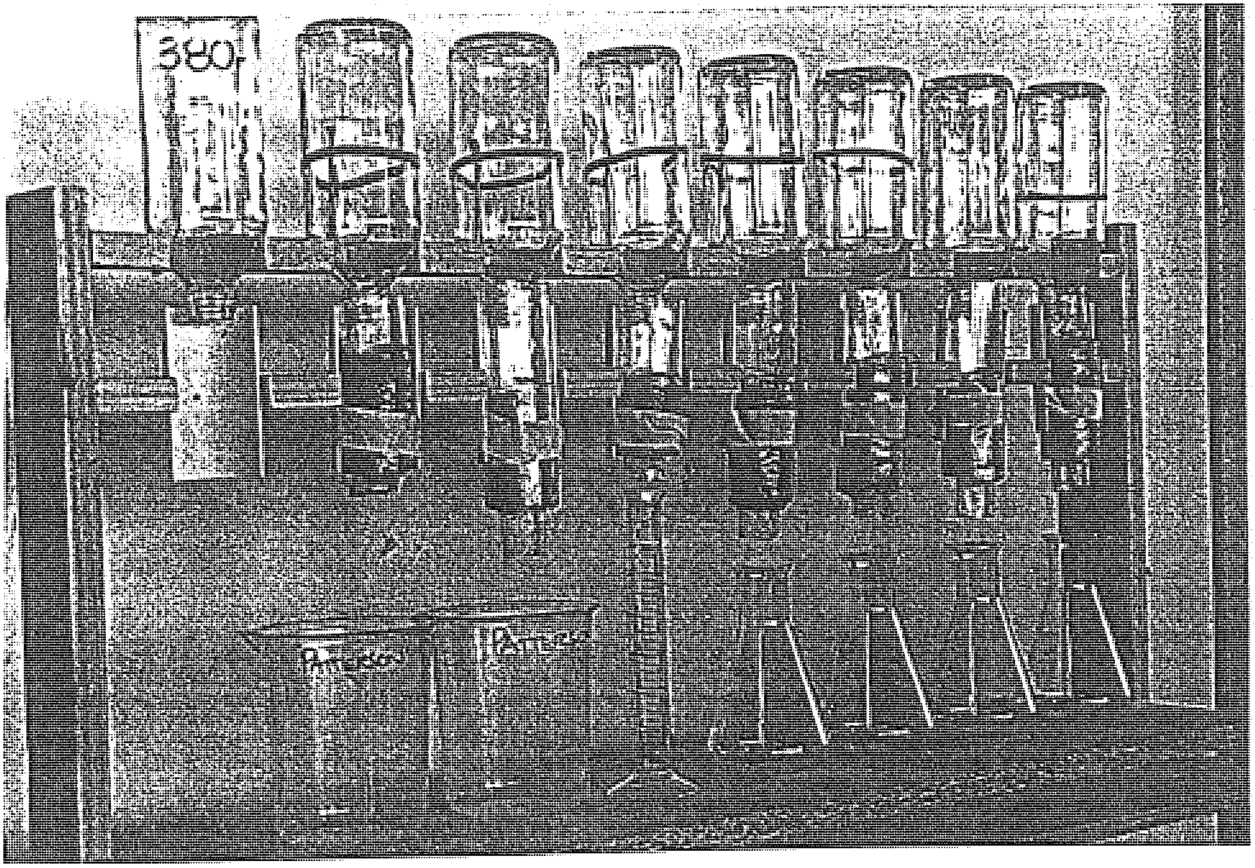

Figure 2. Preparation of undisturbed cores for Ksat measurements

Sub samples from particular depths can be obtained from each sample, while visibly obvious horizon differentiation may delineate the sampling depth. It is preferable that the sub samples are broken from the core so that exposed surfaces represent natural micropores rather than smeared surfaces.

In practice, samples must be obtained at a moisture content between 70% and 100% field capacity. This ensures smearing on the cut surface rather than tearing at the point of separation from the soil body and minimises swelling that may occur upon saturation of the sample. Compression of sample is negligible.

The sample must be inspected for a uniform surface, free of indentations or striations which may provide a preferential path for the infiltrating water. Minor repairs have been successfully made using a firm paste of the same soil. The failure rate of wrapped samples is less than 10%.

## Purpose Designed Measurements

A distinct advantage of the system is that replication of Ksat measurements is obtained for a small increase in labour cost while statistical analysis can be performed on the large number of samples. The major development of the system is the ability to measure Ksat using the effluent under examination, rather than extrapolating results from a measurement obtained with water.

Initially developed for testing domestic septic tank effluent, the implications for other wastewaters have been significant. Where suitably ventilated facilities can be provided, piggery wastes, starch mill wastewater, abattoir wastes and other odorous wastes can be used directly. It is, however, necessary to remove excess solids which may concentrate on the surface of the sample so preventing free infiltration of the liquid into the soil.

Laboratory measurements can be successfully performed using simulated effluents with varying concentrations of dissolved salts, particular cations and/or anions either in isolation or in specific ratios. In preference to using septic tank effluent, the author simulated liquid mixtures with a range of sodium adsorption ratios at a controlled total ionic concentration. The results of part of that research are given below together with a commercial application of the method.

## Septic Tank Effluent Disposal

Domestic septic tank effluent is a mixture of both organic (faeces, urine, food) and inorganic (laundry detergents, soaps, cleaning fluids) chemicals disposed of down the sink or flush toilet and treated simply in the septic tank. Suspended solids carry-over can be reduced through efficient sedimentation and longer detention periods but the chemical constituents continues unabated.

The method outlined above has been used to measure the saturated hydraulic conductivities of a number of different soil types with a simulated septic tank effluent. The inorganic chemistry of the treatment liquid was matched closely to the sodium adsorption ratios and electrical conductivities of a typical range of effluents. The control of pH removed the multi-component effect upon the tests.

## Simulated Effluent Quality

The three levels in sodium adsorption ratio (SAR) reflect the use of powdered washing machine detergents within the house while the water represents the value generally accepted from standard percolation tests. For each test, 15 samples were equilibrated with effluent over periods of up to 4 days after saturation and with quantities of up to 25 pores volumes.

Sodium adsorption ratios of 0, 3, 8, and 15 were chosen. SAR values of 3 reflect households using mostly liquid laundry detergents while SAR 8 is typical of households using powder detergents. SAR 15 is consistent with high use of powder detergents, low consumption of water and high inherent sodium concentrations in the raw water (i.e. high sodium surface or ground waters).

Powder laundry detergents vary considerably in their contribution of sodium to the wastewater. At recommended rates a single washing machine load can add up to 60 grams of sodium to the wastewater. Many liquid detergents also contribute sodium to the effluent, although sodium free liquids are generally available.

The pH was controlled, within normal expected values of 7.5 to 8.3, as the variation in SAR was the parameter under investigation.

## Saturated Hydraulic Conductivity

Figure 3 below indicates the variation of clean water and three effluents of varying sodium adsorption ratios on the treatment of grey-brown podzolic undisturbed soil cores from Armidale, New South Wales. Fifteen surface and subsurface cores were subjected to the test outlined above. The comparison with the clean water (typical of the value derived from the standard percolation test) indicates that under-design of a septic tank drainfield is significant.

The results indicate that while a longer subsurface drainfield may increase the time until failure of the system, failure is inevitable given the dispersion expected from the high SAR. The results of clean water following a treatment of high SAR effluent have not yet been finalised, however, interim results indicate that additional dispersion with the clean water again decreases saturated hydraulic conductivity. This phenomenon is well understood in relation to rainwater following applications of irrigation water of high sodic qualities.

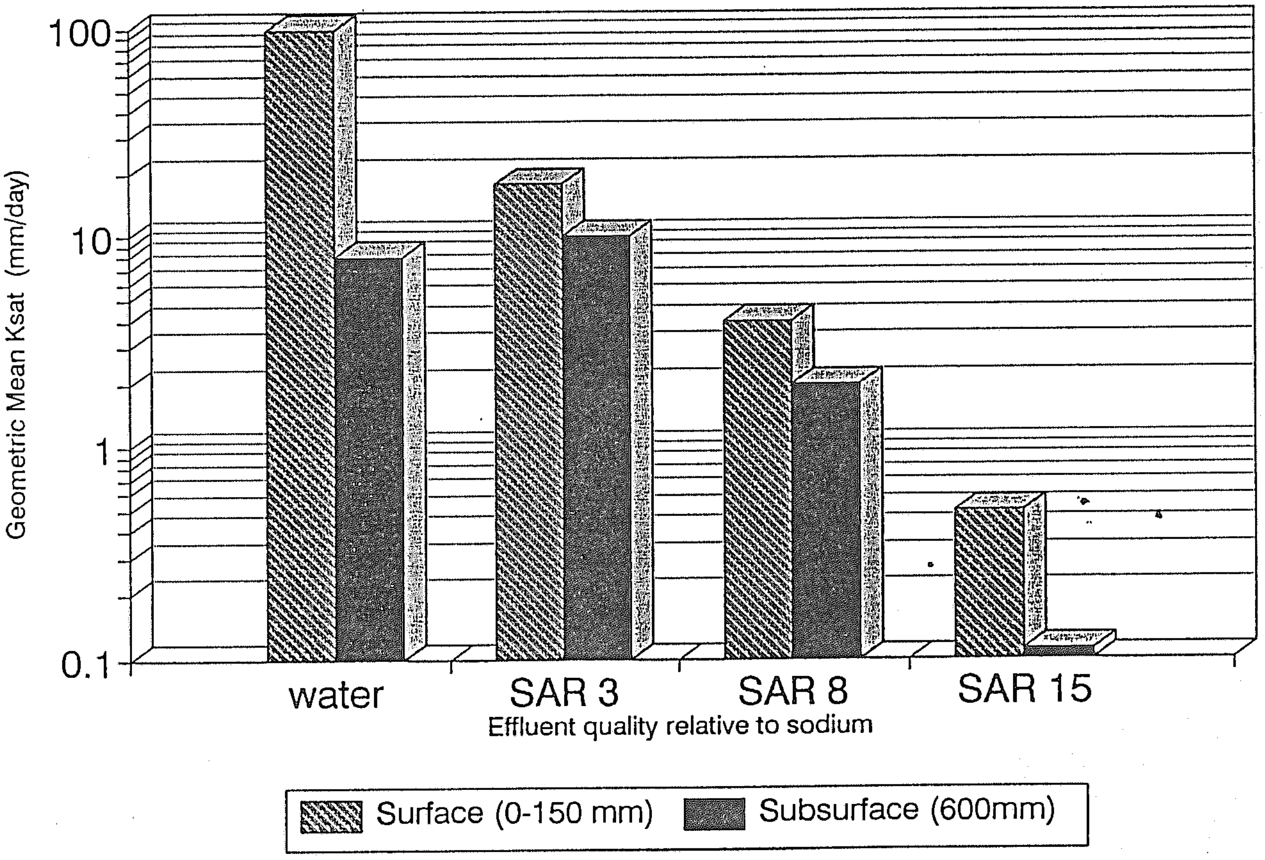

Figure 3. Application of simulated septic tank effluent to soil cores (grey brown podzolic)

## COMMERCIAL APPLICATION

### Starch Mill Wastewater Disposal

In a recent project Patterson (1990) measured Ksat on 500 undisturbed soil cores under laboratory conditions. The samples were obtained from the 100-150 mm and 700-750 mm portion of 90 soil cores and 15 replicate samples for each depth were subjected to one of three treatments. Following wrapping in the heat shrink plastic sleeve as described above, samples were treated with clean water, a raw effluent from a manufacturing industry (starch mill) or a lime amended effluent from the same factory.

The results indicated that the amended effluent provides a high level of protection to the environment through very low Ksat values, whereas the results from the clean water trial indicated a high potential for contamination from the field disposal of the starch mill wastewater. The effluent had chemical characteristics similar to septic tank effluent and similar results could be expected for septic tank effluent disposed of on similar soils.

TABLE 1.

WASTEWATER QUALITY FROM STARCH MILL OPERATION

| Parameter | Water | Raw Effluent | Amended Effluent |
|---|---|---|---|
| pH | 6.9 | 3.0 | 10.7 |
| SAR | 0 | 3.4 | 1.6 |
| EC ($uScm^{-1}$) | 62 | 1209 | 1560 |
| $Na^+$($mgL^{-1}$) | 1 | 113 | 114 |

The results indicate the variation in Ksat values for the three treatments. Previous testing by the starch mill management had been carried out using double ring infiltrometers replicated three times using lime amended effluent only. Due to difficulties of field testing, no comparison among the three effluents was made, yet management decisions were proposed from the few results. In the current undisturbed measurements, the statistical results provided a clearer picture of the in-field disposal operation and the requirements for environmental protection.

The graph below indicates the variation for both the surface (100-150 mm) and the subsurface (700-750 mm) cores of an alluvial derived Vertisol in Tamworth, N.S.W.. Fifteen samples from each horizon for three locations were subjected to one of three treatments (clean water, effluent, amended effluent). The results, graphically represented in Figure 4, indicate the broad differences and the loss of infiltrative capacity with the effluent intended for surface disposal (that is, the lime amended effluent) compared with the other two. The statistical analysis given in Table 2 suggests that the high variability within the samples must be taken into account in any management plan by way of best and worst case designs. In previous research the factory management used data from only three surface tests. Sun paddock was the control, Holmwood has been surface irrigated with effluent to 5 years while No.2 has been used over last 25+ years.

TABLE 2.

STATISTICAL ANALYSIS OF KSAT FOR 3 TREATMENTS FOR EFFLUENT DISPOSAL

Under simulated rainfall

| Location | | Median (mm/day) | average (mm/day) | Standard Deviation | Coeff. of Var. | 95% C.I. (mm/day) |
|---|---|---|---|---|---|---|
| Holmwood | surface | 30 | 89 | 112 | 131% | 66 -104 |
| | subsurface | 112 | 155 | 106 | 67% | 137 -174 |
| Sun | surface | 9 | 53 | 57 | 107% | 39 - 67 |
| | subsurface | 70 | 121 | 103 | 85% | 103 -139 |
| No.2 | surface | 6 | 15 | 7 | 98% | 18 - 22 |
| | subsurface | 52 | 96 | 8 | 83% | 80 -113 |

The method has now been adopted by a number of state agencies due to the ease of replication and the facility for testing with the actual effluent under examination. Further testing of the sample can measure the effects of one effluent following another or of periods of partial drying before reapplication.

The application is particularly important where soils treated with a particular effluent, as above, are subjected to rainfall which alters the ionic quality of the soil water regime. It is possible that dispersion, following wastewater disposal may dictate a particular management decision. In the case above, dispersion was not a concern, while the loss of saturated hydraulic conductivity was an advantage in avoiding groundwater contamination.

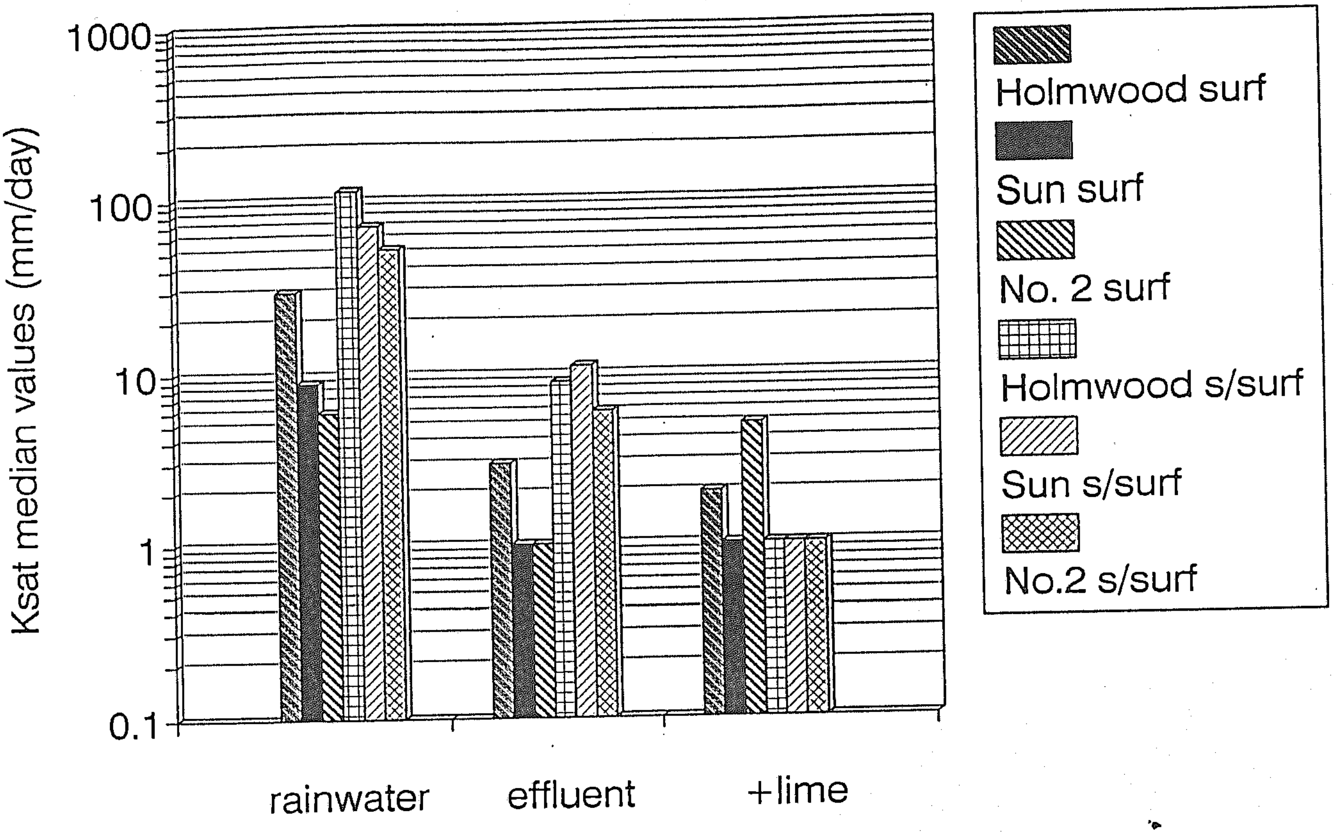

Figure 4. Ksat measurements for three location and three treatments

The continued loss of saturated hydraulic conductivity from the lime amended effluent is consistent with wastewater of high pH which is known to induce dispersion. The failure of the test to indicate severe loss of hydraulic conductivity when clean water was applied to soil having a long history of starch mill waste disposal was due to the high base saturation of the soil preventing dispersion. This has been quantified in recent research on the soil cores.

## CONCLUSION

The disposal of wastewater to the soil environment can be simulated in a more statistically correct approach through the use of undisturbed cores. The vertical percolation of water and other effluents, in particular septic tank effluent, has been tested using plastic wrapped undisturbed cores. The results indicate that the method provides a range of Ksat which allow comparison of effluent treatments at various depths within the profile. The method is both time efficient and highly reproducible under laboratory conditions.

Through the use of actual effluents or simulated chemical equivalent solutions the saturated hydraulic conductivity over a combination of effluent disposal mechanisms can be replicated to determine efficient management strategies. The loss of Ksat through pH effects can be directly evaluated (a separate research paper on this aspect is in development) which may involve the chemical amelioration of the effluent prior to disposal.

Amelioration of soil to increase or decrease Ksat, can likewise be instigated to provide the environmental protection required. In the case of the septic tank effluent, the design criteria was to dispose of the water in a subsurface drainfield without failure resulting in the surfacing of effluent. For the disposal of the starch mill waste, the aim was to dispose of the effluent through evapotranspiration without recharge to the groundwater, that is through poor Ksat.

The method outlined above demonstrated the changes in saturated hydraulic conductivity for each of the individual aims of the two projects. The cost of sampling in sufficient numbers to provide valuable statistical data has been reduced through rapid sampling and sub-sample preparation.

## REFERENCES

Australian Bureau of Statistics (1987). Domestic Water Use in New South Wales. Aust.Bureau Stats., Sydney.

Bligh, K. (1978). The use of ring infiltrometers for estimating runoff in South Western Australia. Conf. Ag.Eng., Inst.Engg.Aust.

Brouwer, J. and Bugeja, R.M. (1980) Land Capability for Septic tank Effluent Absorption Trenches. Report A.W.R.C. Project 79/118 SRWSC, Victoria.

Jayawardane, N.S. (1979). An equivalent salt solution method for predicting hydraulic conductivities for different salt solutions. Aust.J.Soil Res.,17:423-428.

Loveday, J. (Ed) (1974). Methods for Analysis of Irrigated Soils. Commonwealth Bureau of Soils, London.

McGauhey, P.H. and Krone, R.B. (1967) Soil Mantle as a Wastewater Treatment System. Sanitary Engineering Research Laboratory, Uni.California, Berkeley.

Means, R.E. and Parcher, J.V. (1963). Physical Properties of Soils. Merrill Publ.Co., Ohio.

Otis R.J. (1977). On-site Disposal of Small Waste Water Flows. Uni Wisconsin, Madison.

Patterson, R.A. (1988). Undisturbed Cores for Hydraulic Conductivity Analysis Proc.Nat. Soils Conf., Canberra, 9-12 May, 1988. Aust.Soc.Soil Sci.Inc., p226.

Patterson, R.A.and Cass, A. (1988). Bulk Density Measurements using Hydraulic Soil Sampler Proc.Nat.Soils Conf., Canberra, 9-12 May, 1988. Aust.Soc.Soil Sci. p225.

Patterson, R.A. (1990). Scott's Road Infiltration Testing: A report for Goodman Fielder Mills. Lanfax Laboratories, Armidale.

Shainberg, I., Rhoades, J.D. and Prather, R.J. (1981). Effect of Low Electrolyte Concentration on Clay Dispersion and Hydraulic Conductivity of a Sodic Soil Soil Sci.Soc.Am.J 45:273-277.

State Pollution Control Commission (1987). Pollution control manual for urban stormwater (draft) SPCC, Sydney.

Talsma, T., and Hallam, P.M. (1980). Hydraulic conductivity measurements for forest catchments Aust.J.Soil Res.,18:139-148.

Winneberger, J.H.T. (1984) Septic Tank Systems: A Consultant's Toolkit. Volume 1. Subsurface Disposal of Septic Tank Effluents Butterworth Publ., Boston.